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Fingerprint Image Quality Metrics That Guarantees Matching Accuracy

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Amane Yoshida & Masanori Hara

Acknowledgements

FVC2002 and 2004 fingerprint test sets are used in this evaluation.

Most fingerprint images shown in this presentation are from FVC2002 DB3 and NIST Special Data Base #27.

Contribution of these databases on fingerprint matching researches is notable.

Patents

- USP5,040,224 - Fingerprint Core (UCX) Extraction
- Pending - Japanese Gan2006-050391 - Pattern Area Extraction

Preliminary Question

- Given:
  - A set of fingerprint images
  - Its accuracy is less than 100%

- Question:

  How much proportion of the poorest quality images do we need to reject in order to guarantee 100% accuracy?

Contents

- **PART 1:**
  Essential Factors and Key Technologies for Quality Metrics

- **PART 2:**
  Fingerprint Image Quality Metrics That Guarantees Matching Accuracy

Part 1:
Essential Factors and Key Technologies for Quality Metrics

- Factors to Determine Quality
- Operational Needs for Quality Factors
- Objectives for Quality Factors
- Positioning Quality for Common Area

Masanori Hara

1. Factors to Determine Quality

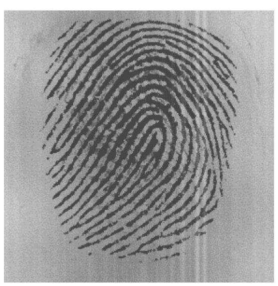
1) Ridge Quality or Ridge Clearness

2) Captured Image Size

Flat images are much smaller than rolled images

3) Captured Image Position

Critical on flat images



Factors to Determine Quality – Continued#1

4) Quality and Quantity of Matching Features

Dependant on the specific Matching Algorithm

"Quality Metrics" cannot be free from Matching Algorithm!

Minutia Matching → Sample B: Higher Chance of Hit

Factors to Determine Quality – Continued#2

5) Orientation of Image

Not critical because Matching Algorithm can compensate with additional cost

6) Distortion of Image

Difficult to assess without actual matching

7) Others

Which Factor is Most Important?

→ Depends on Operational Needs and Objectives

2. Operational Needs for Quality Factors

a) Verification → Subject Wishing "Hit" (Positive ID System) or
Identification → Subject Wishing "No-Match" (Negative ID System)
b) Uncooperative or Cooperative (Voluntary) at Capture
c) Unsupervised, Supervised or Forced at Capture
d) Flat or Rolled Image

Focused on:

a) Identification (1:N) - to find bad guys
b) Uncooperative - to degrade image quality
c) Supervised - to restrain bad behavior
d) Flat image - for easier use

e.g. Entry Check for Homeland Security

3. Objectives for Quality Factors

a) Criteria for Rejection or Acceptance at Capture (FTA)
→ Stricter Condition Suggested for Recapture

b) Criteria for Enrollment or Registration (FTE)
→ Ideal to have large and perfect image

c) Criteria for Search Data
→ OK to accept small (partial) area if such area is registered on file-prints

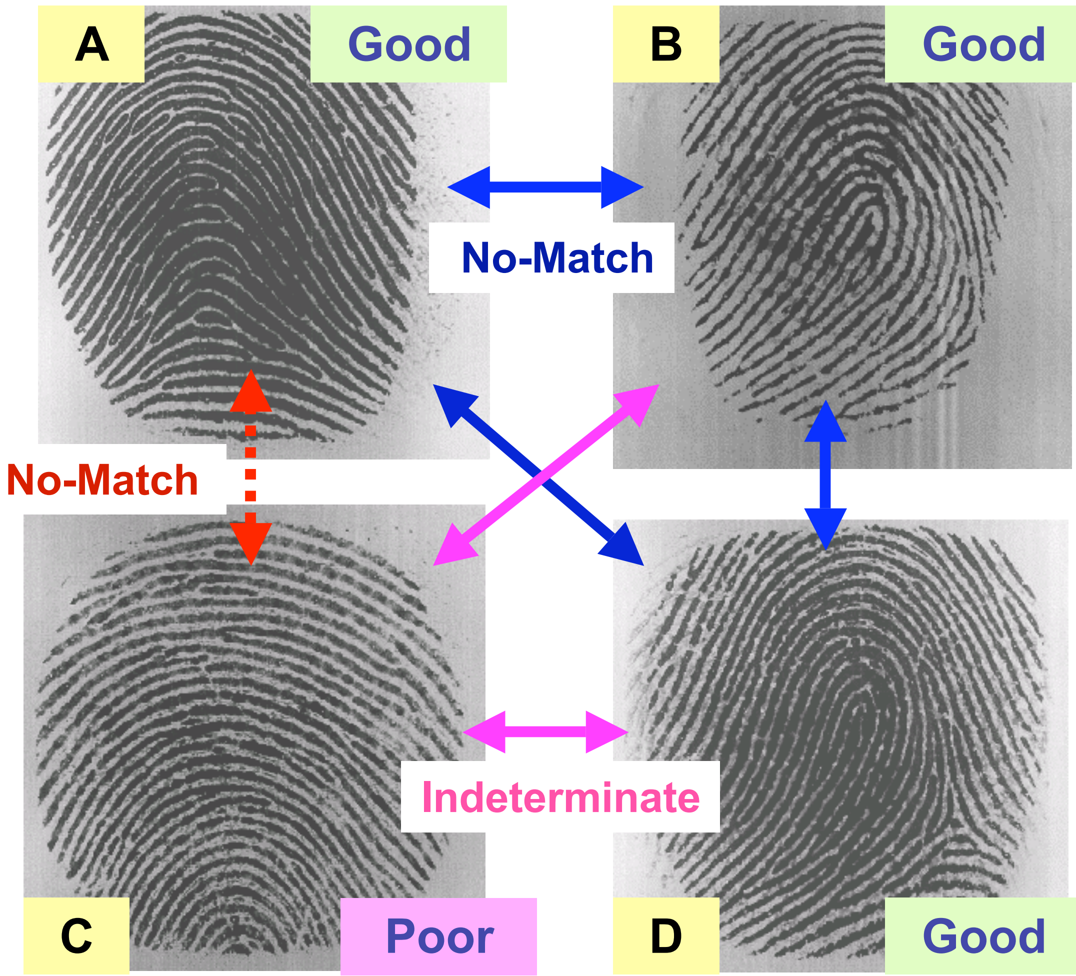
d) Criteria to Assure "Determinate No-Match"
→ Subject NOT registered in Data Base

Capture Image Position - One of Most Important Factors as

a) Rejection Criteria especially for Flat Images
d) Assuring Criteria for Determinate No-Match

And Important to Guarantee Matching Accuracy

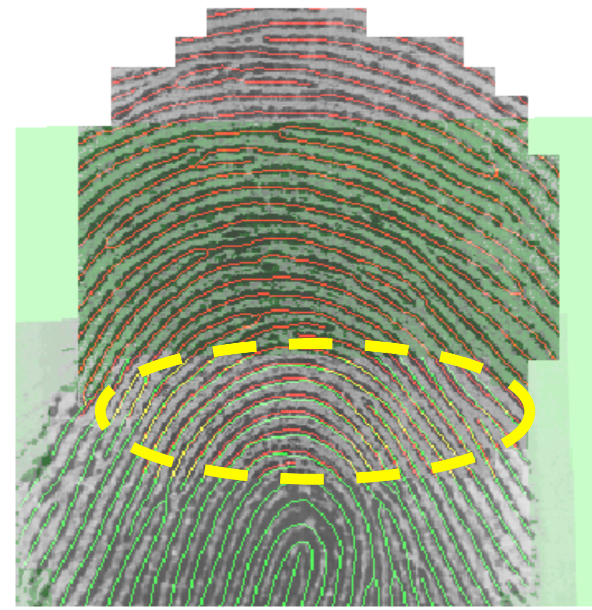
Essential Factors and Key Technologies for Quality Metrics



Quiz Time

Any Pair?

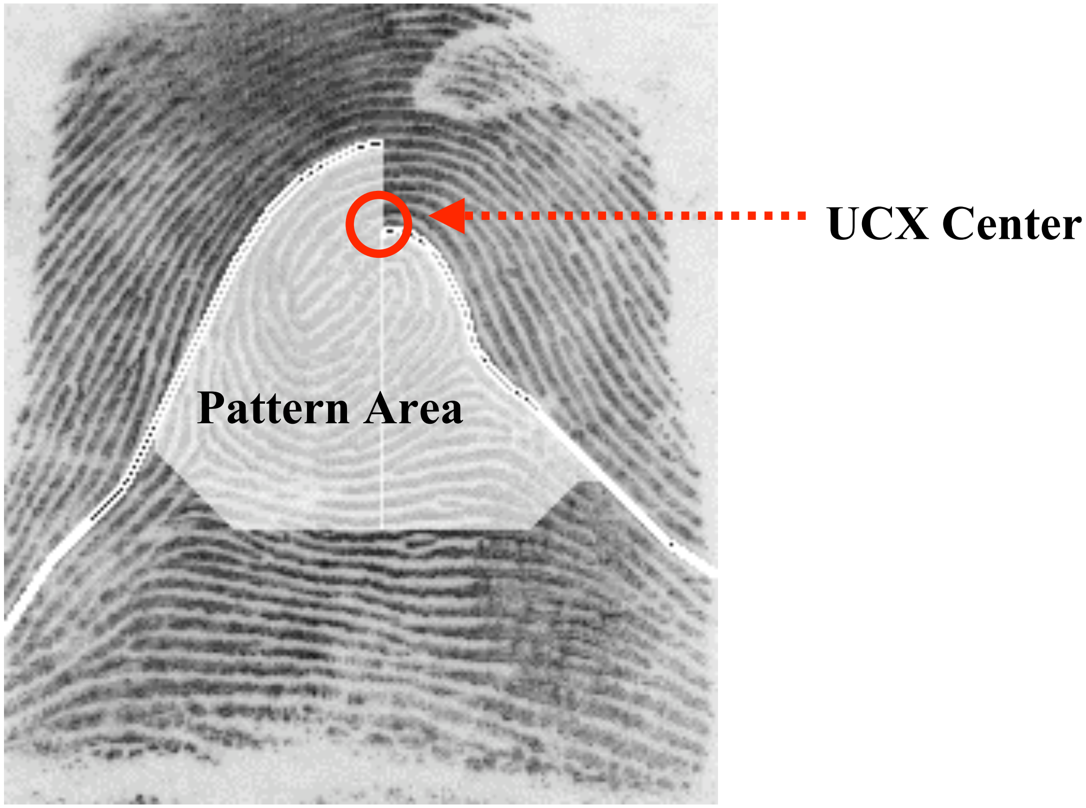
Answer: C & D



a) Two “Good Positioning” Images & Score 0 → Determinate No-Match

b) “Poor Positioning” Image Involved & Low Score → Indeterminate

4. Positioning Quality for Common Area

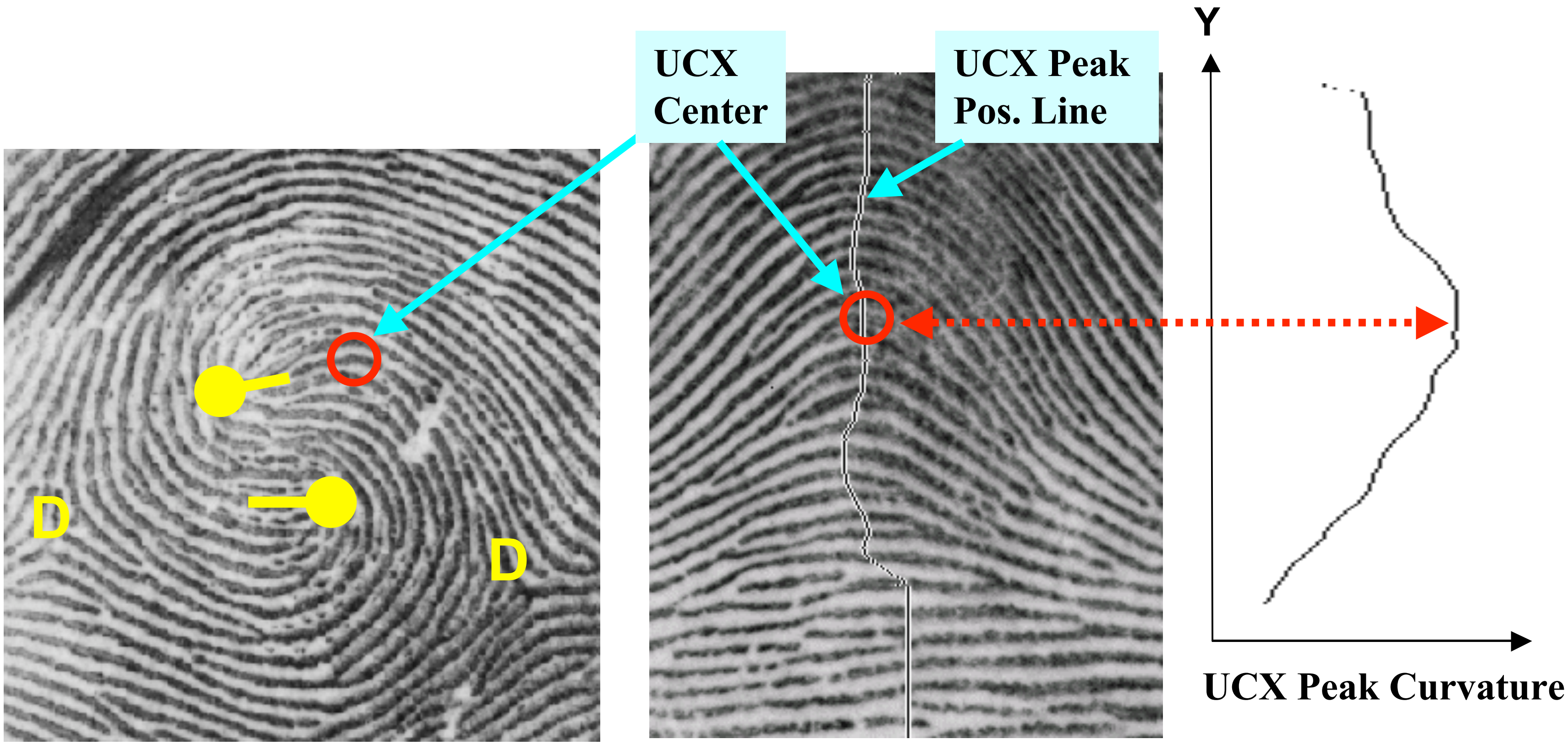


- **Pattern Area (PA): Ideal Candidate for Common Area**
- **UCX Center (Upward Convex): Key Position for PA**

(a) UCX (Upward Convex) : New Definition for Center

UCX: Center of Peak Curvature Area with Upward Convex Shape Ridges

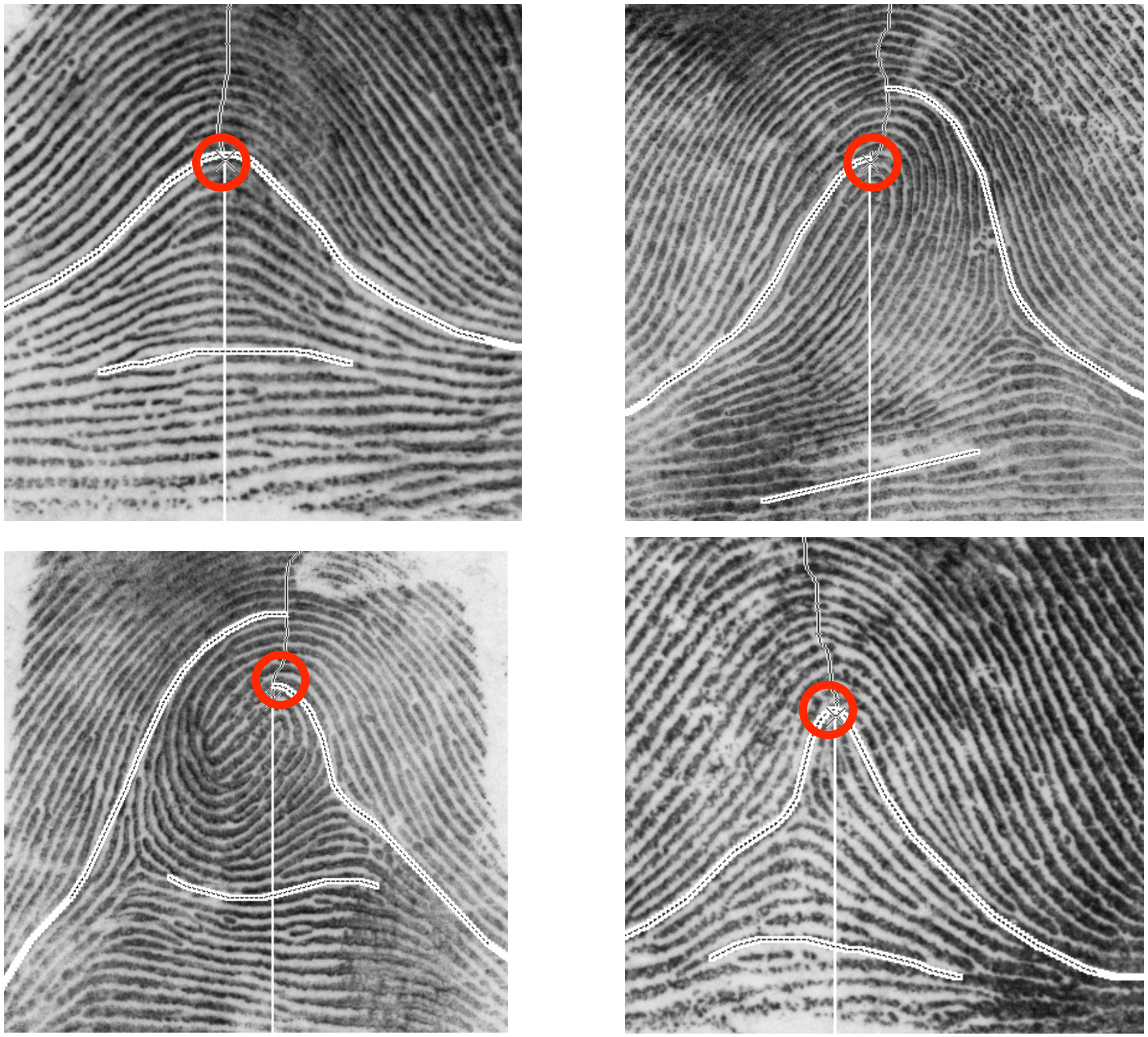
Unlike Traditional Core, UCX is defined on Arches and more Consistent



Essential Factors and Key Technologies for Quality Metrics

(b) Pattern Area : Contains Characteristic Ridges

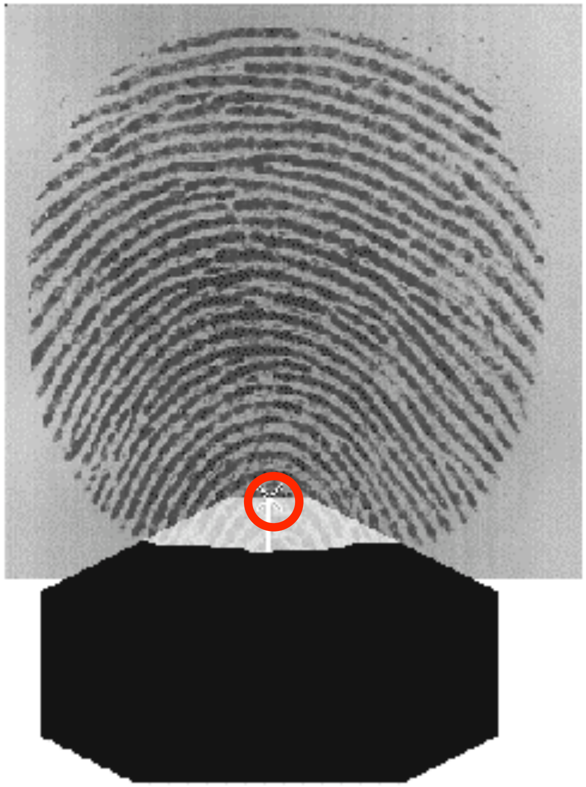
Samples of Extracted UCX Center and Pattern Area Slope

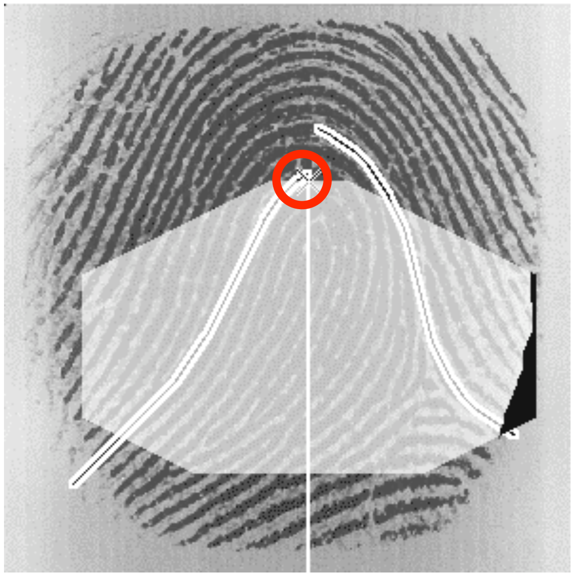


UCX Center

Essential Factors and Key Technologies for Quality Metrics

(c) Positioning Quality Samples based on UCX & Pattern Area





Positioning Quality → Poor
1) Low Confident UCX
2) Pattern Area Not Defined
3) Little Clear Ridge Area in PA

Positioning Quality → Good
1) High Confident UCX
2) Pattern Area Defined
3) Large Clear Ridge Area in PA

Part 2:
Fingerprint Image Quality Metrics that Guarantees Matching Accuracy

- Defining Quality
- Measuring Quality
- Assessing Quality

Amane Yoshida

Defining Quality

- **Definition**
  - ***A guarantor of matching accuracy*: Selectively matching high-quality images yields high accuracy, and vice versa**
  - **Placed an emphasis on the *matchability* of a single search-file pair**

Measuring Quality – Overview

- Rated on a 0-100 scale, where 0 is the lowest quality and the 100 is the highest quality
- Nonlinear combination of four independent indices
  - Ridge quality with its area size
  - High-confidence minutiae count
  - Positioning quality for common area
  - Distortion tolerance

Measuring Quality – Positioning

- **Common area based on UCX and pattern area**
- **It is essential for a mate pair to have *sufficient pattern area in common around their UCXs* to be successfully matched**

Measuring Quality – Distortion Tolerance

- The level of tolerance against distortion evaluated by actual matching
- Proportional to the score between an image and its pseudo search image

Original image

VS

Pseudo search image

The pseudo image - produced from original image through cropping, distortion effect, etc.

Measuring Quality – Fusion

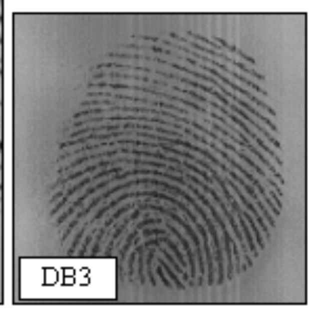
- **All four indices are nonlinearly combined to get an overall quality**
- **Designed in such a way that high quality values are awarded if high matching accuracy is expected**

Assessing Quality – Datasets (1/3)

- FVC2002 Databases (4 sets)
- Total of 800 images per database
  - 100 fingers, 8 impressions each,
  - 2,800 mate pairs

Optical
500dpi

Optical 569dpi



Capacitive
500dpi

Synthetically generated
500dpi

Assessing Quality – Datasets (2/3)

■ Matcher used: SDK H3

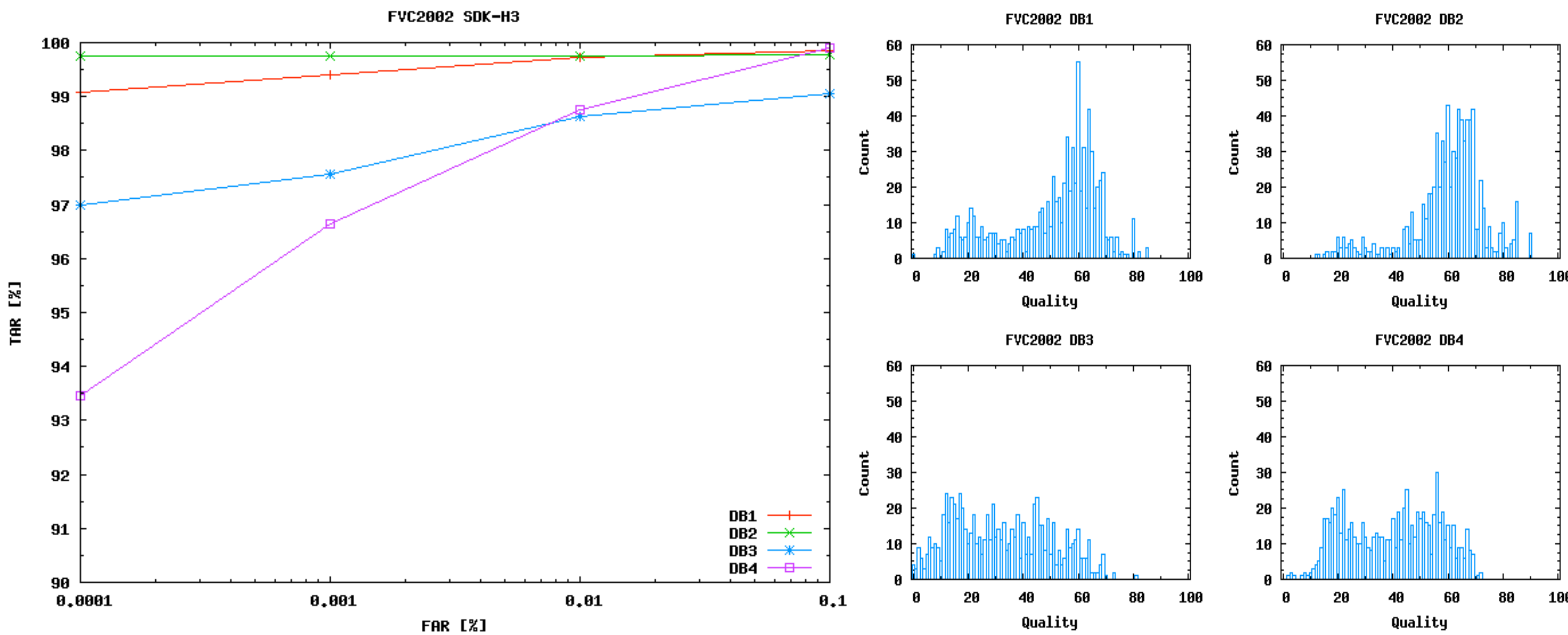
	Speed		TAR at FAR=0.01%			
	Match	FE	DB1	DB2	DB3	DB4
SDK H3	**H-equiv.**	**Slow**	**99.64**	**99.75**	**98.38**	**98.71**
SDK H2	H-equiv.	H-equiv.	99.45	99.79	95.18	97.38
SDK H	See NISTIR7151		99.02	99.68	92.13	96.36

SDK H2 & H3: Enhanced versions of SDK H (equivalent match speed)
SDK H: Submitted to NIST in December 2003

- Evaluation method: Based on NIST SDK evaluation study
- Not FVC-equivalent: identification rather than verification (i.e., aimed to fulfill "high match speed" requirement)
- TAR Calculation: 5,600 (800x7) mate pairs
- FAR Calculation: 633,600 (800x792) non-mate pairs

Assessing Quality – Datasets (3/3)

- FAR vs TAR (SDK-H3)



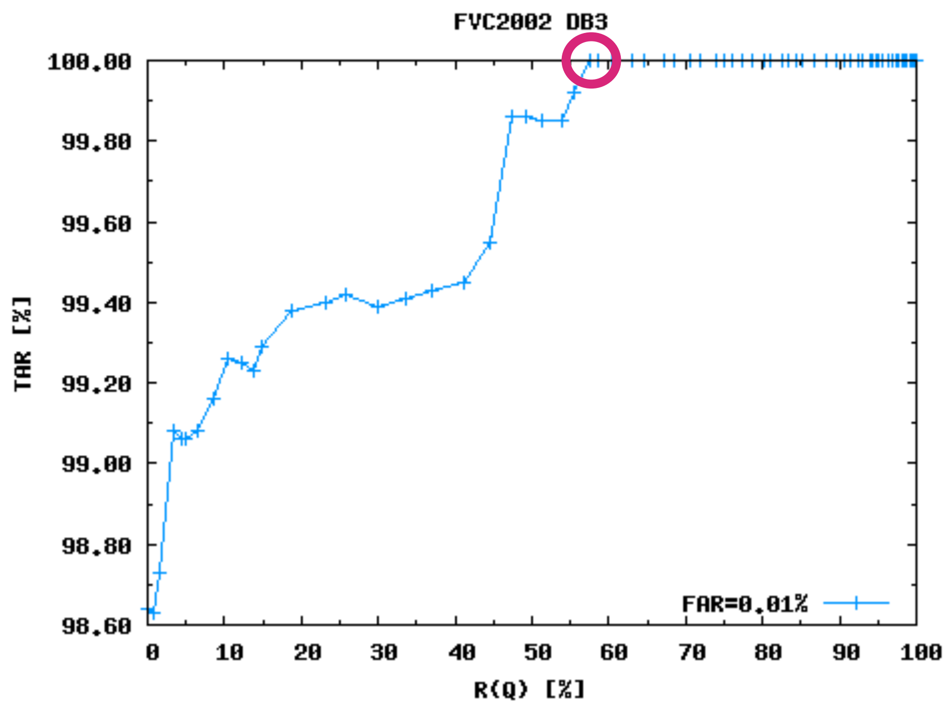
Assessing Quality – Pruning (1/5)

- **Recall that the higher the quality, the higher matching accuracy**
- **Rejecting low quality data should yield a higher TAR**
- **Rejection rule:**
  - if $\min(Q_{\text{search}}, Q_{\text{file}}) <= Q_{\text{th}}$ then reject
  - **This rule can be applied separately to search or file prints**
- **The percentage R of the data to be rejected is a function of Q_{th}**

Assessing Quality – Pruning (2/5)

R(Q) vs TAR

Q_{th}	$R(Q_{th})$ [%]	# of Hits	TAR [%]
N/A	**0.00**	5524/5600	**98.64**
0	**0.89**	5474/5550	**98.63**
1	**1.54**	5444/5514	**98.73**
2	**3.39**	5360/5410	**99.08**
⋮	⋮	⋮	⋮
22	**53.86**	2580/2584	**99.85**
23	**55.54**	2488/2490	**99.92**
24	**57.64**	2372/2372	**100.00**
⋮	⋮	⋮	⋮



If the quality of the data given is greater than 24, then TAR=100% is "guaranteed"

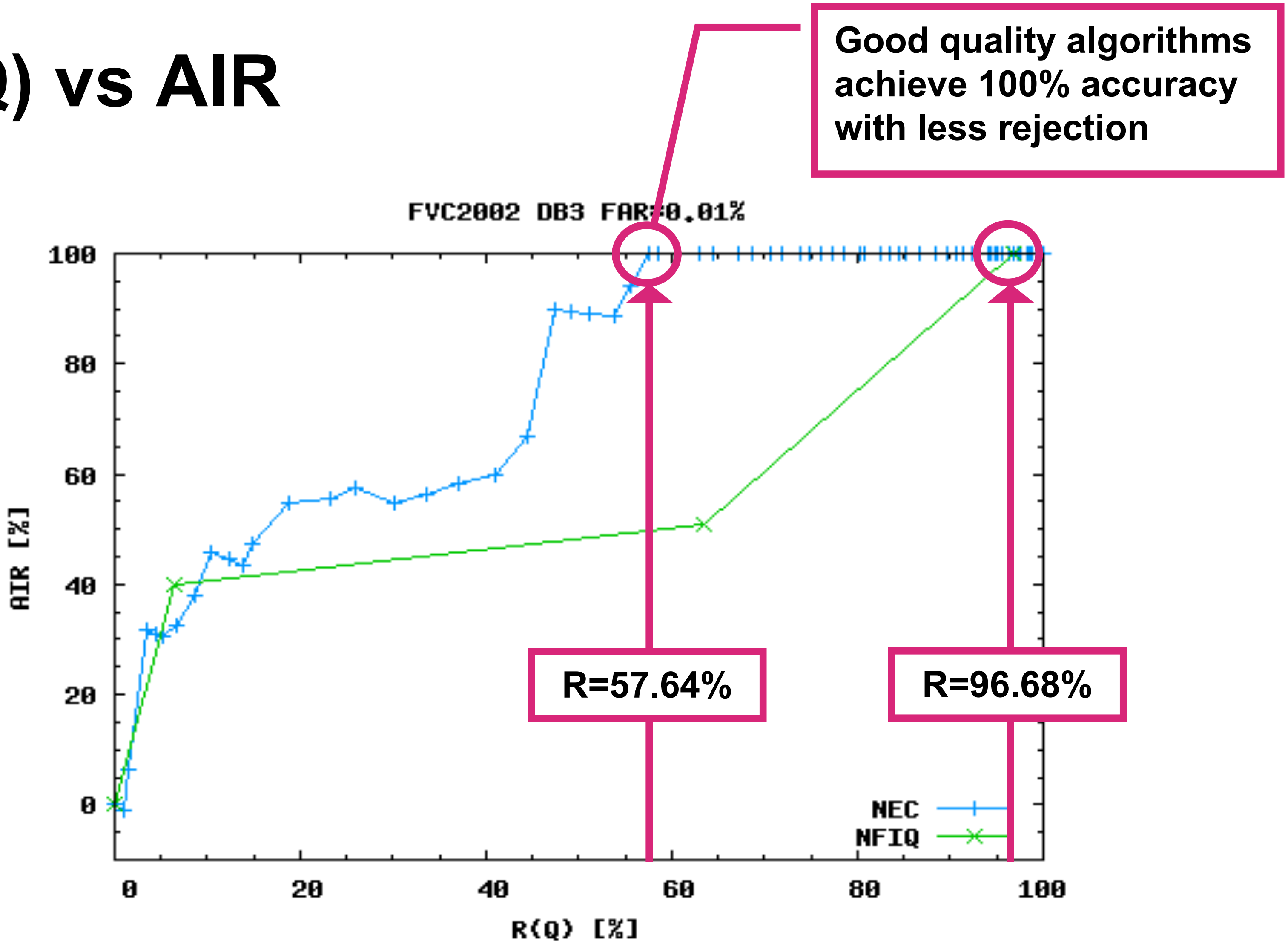
Assessing Quality – Pruning (3/5)

- **Accuracy Improvement Rate (AIR)**
  - **Degree of improvement with respect to the reference (i.e., initial) accuracy when pruned**
  - $AIR_R = (TAR_R - TAR_0)/(1 - TAR_0)$

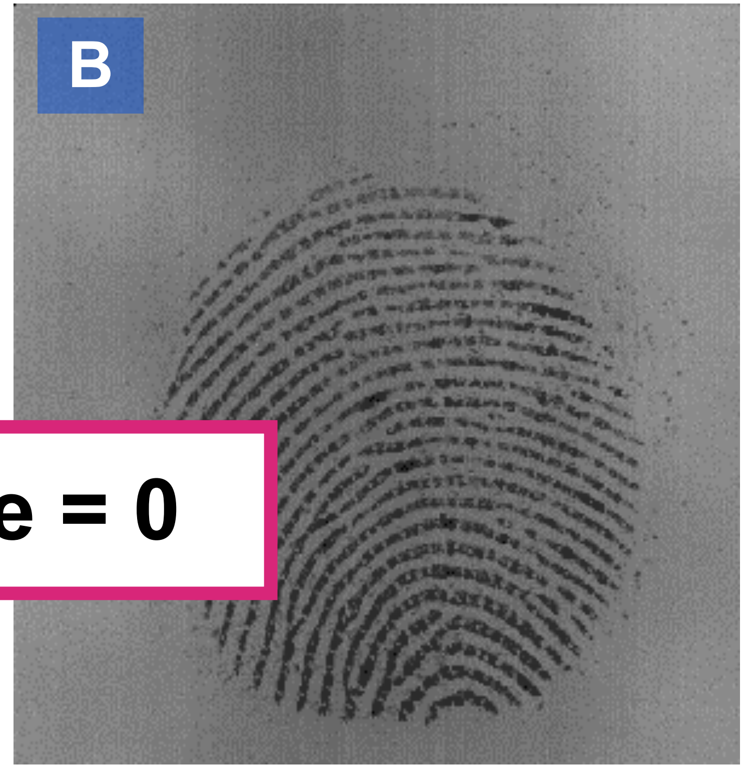
where TAR_0 is the initial accuracy and TAR_R is the subsequent accuracy after rejecting R% of all data (See *Appendix A*)

Assessing Quality – Pruning (4/5)

- R(Q) vs AIR



Assessing Quality – Pruning (5/5)



Score = 0

$Q_{NFIQ} = 2$ (2nd best)
$Q_{NEC} = 29$ (fair)

$Q_{NFIQ} = 2$ (2nd best)
$Q_{NEC} = 16$ (poor)

Image B should have a lower rank so that it will be rejected in the early stage

Conclusion

- Quality metrics is predictive of the matcher performance and hence *guarantees accuracy*
- It is essential for a mate pair to have *sufficient pattern area in common* to be successfully matched
- Quality measure and matcher are *mutually dependent* and thus cannot be considered separately

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References

NISTIR 7151 *NIST Fingerprint Image Quality*

NISTIR 7221 *Studies of One-to-One Fingerprint Matching with Vendor SDK Matcher*

C. Watson, et al; *NIST Fingerprint Image Software*

http://www.itl.nist.gov/iad/894.03/databases/defs/nist_nfis.html

FVC2002 – Second Fingerprint Verification Competition 2002,

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FVC2004 – Third Fingerprint Verification Competition 2004,

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Hicklin, Reedy; *Implications of the IDENT/IAFIS Image Quality Study for Visa Fingerprint Processing*, October 2002,

http://www.mitretek.org/NIST-IQS.pdf

Chen, Dass, Jain; “Fingerprint Quality Indices for Predicting Authentication Performance”; 2005,

http://biometrics.cse.msu.edu/ChenDassJainFpQuality_AVBPA05.pdf

D. Simon-Zorita, J. Ortega-Garcia, J. Fierrez-Aguilar and J. Gonzalez-Rodriguez; *Image quality and position variability assessment in minutiae-based fingerprint verification*; December 2003

http://fierrez.ii.uam.es/docs/2003_IEEProcVISP_QualityFingerprint_Simon.pdf

Appendix A: Sample AIR Calculation

- **Ex) 5%-pruning (FVC2002 DB3)**

$$TAR_0 = 0.980$$

$$TAR_{0.05} = 0.999$$

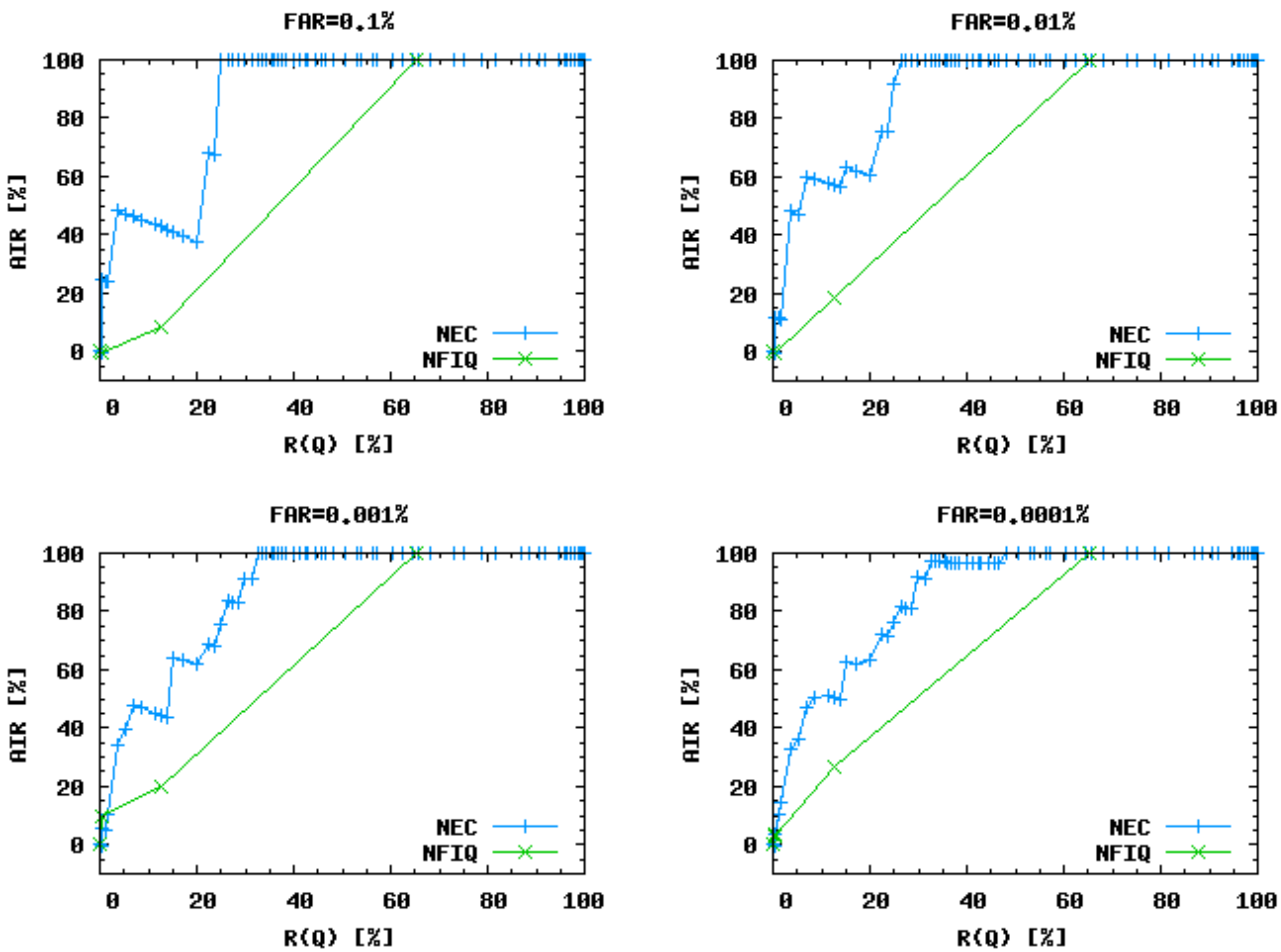
$$AIR_{0.05} = \frac{TAR_{0.05} - TAR_0}{1 - TAR_0}$$

$$= \frac{0.999 - 0.980}{1 - 0.980}$$

$$= \mathbf{0.950}$$

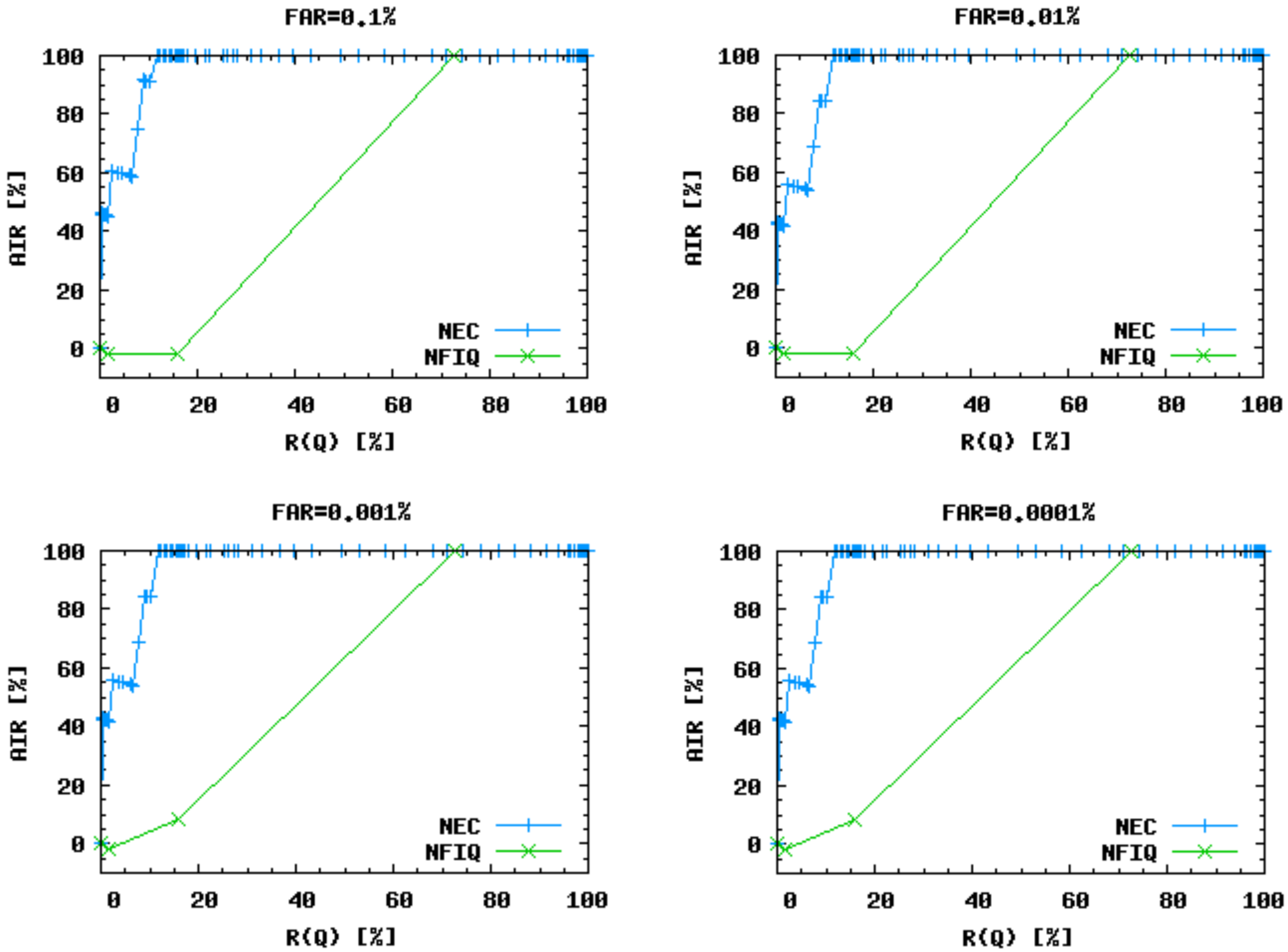
Appendix B: FVC2002 (1/5)

- **DB1: Comparison over varying FAR**



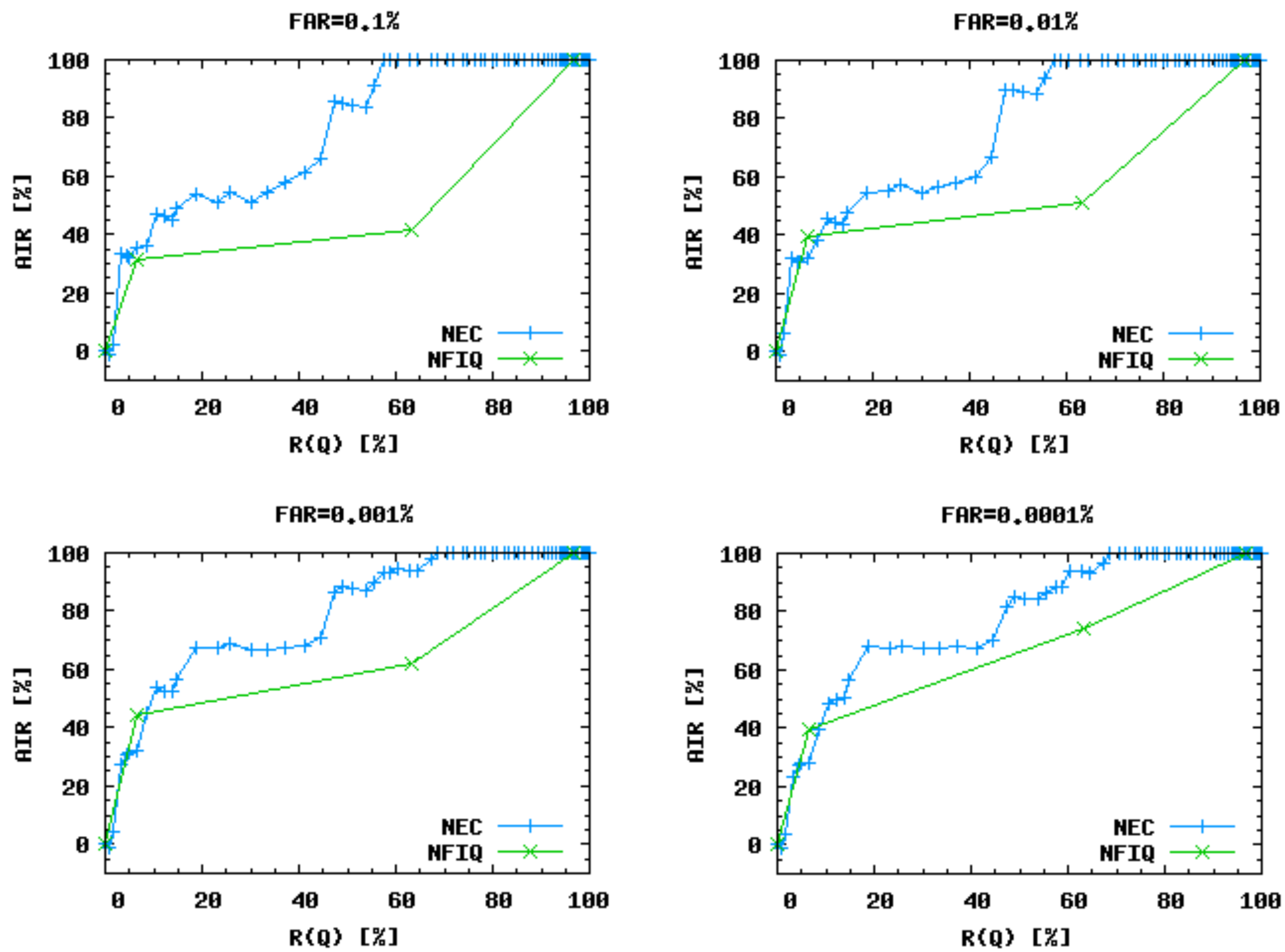
Appendix B: FVC2002 (2/5)

- **DB2: Comparison over varying FAR**



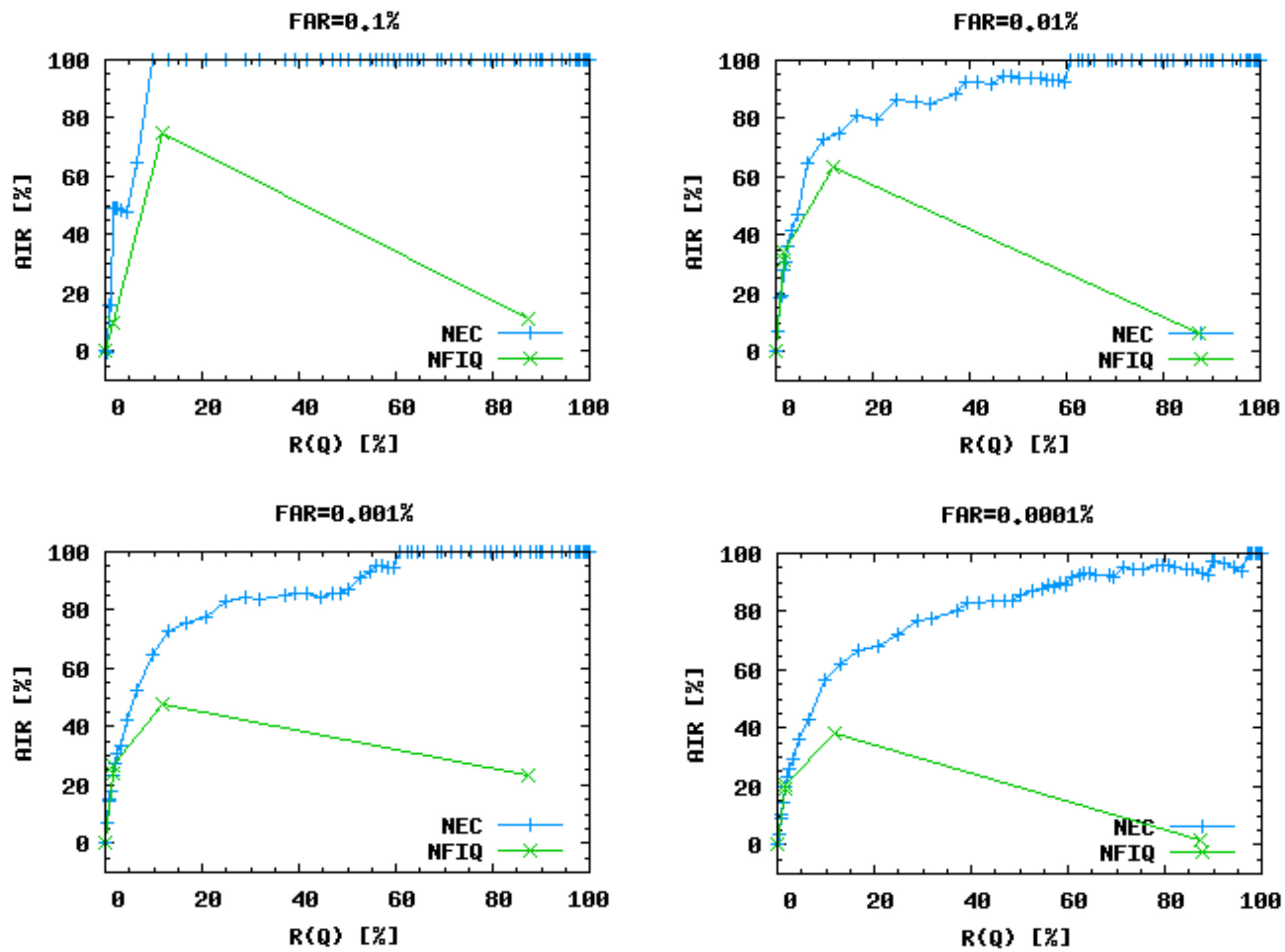
Appendix B: FVC2002 (3/5)

- **DB3: Comparison over varying FAR**



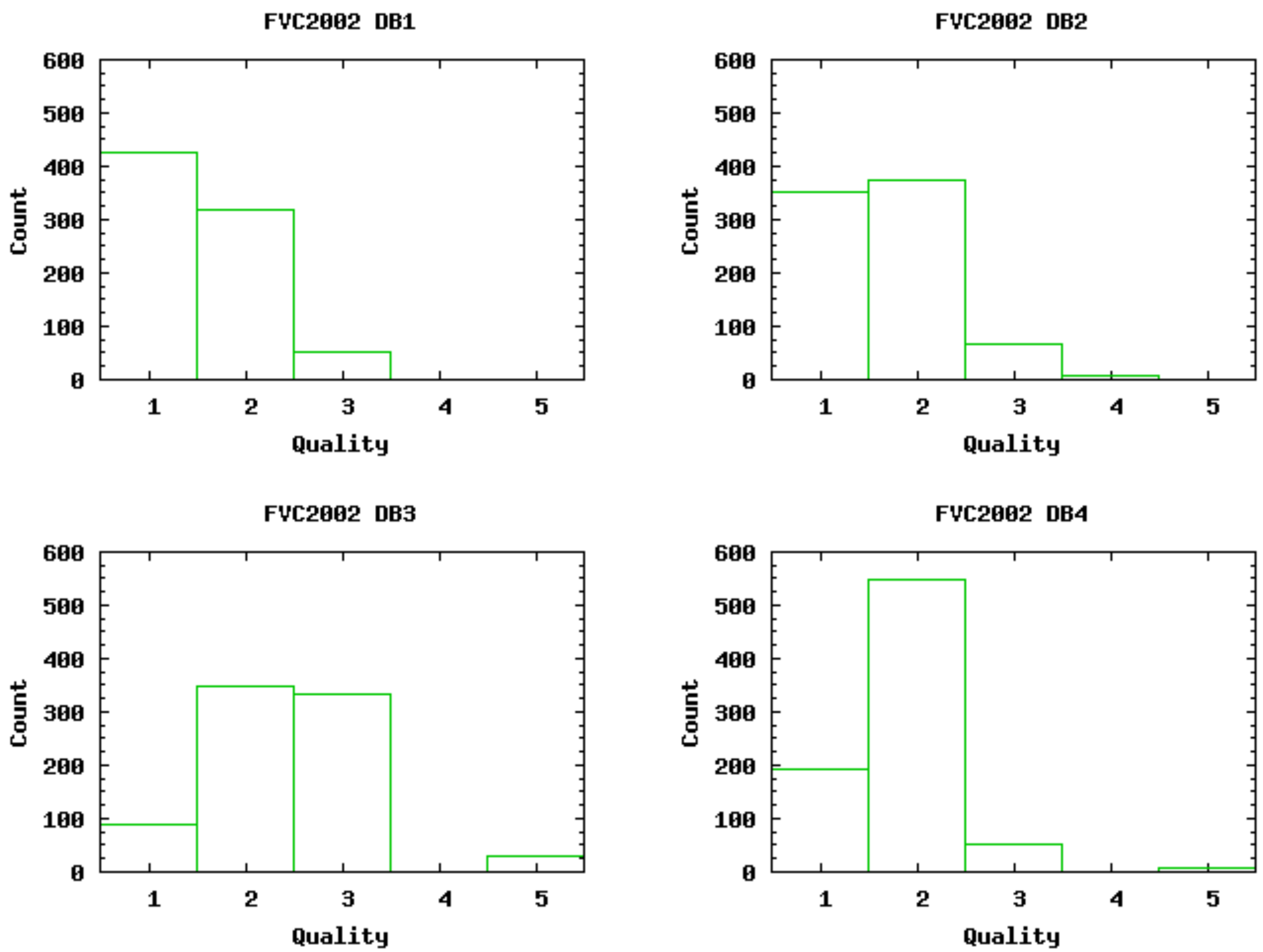
Appendix B: FVC2002 (4/5)

- DB4: Comparison over varying FAR



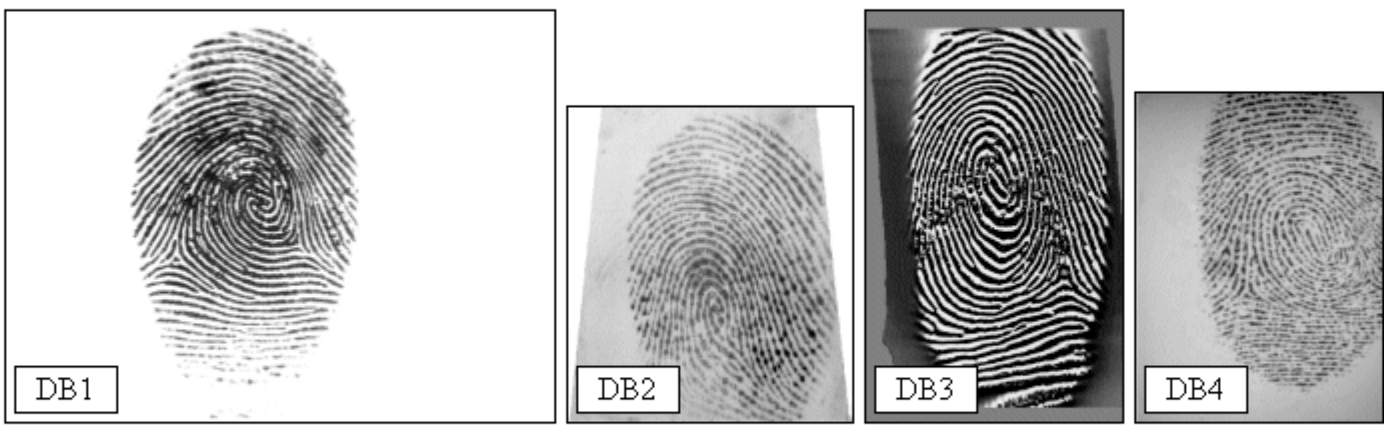
Appendix B: FVC2002 (5/5)

- NFIQ Quality Distribution



Appendix C: FVC2004 (1/8)

- FVC2004 Databases (4 sets)
- Total of 800 images per database
  - 100 fingers, 8 impressions each,
  - 2,800 mate pairs



Optical 500dpi | Optical 500dpi | Thermal-sweeping 512dpi | Synthetically generated 500dpi

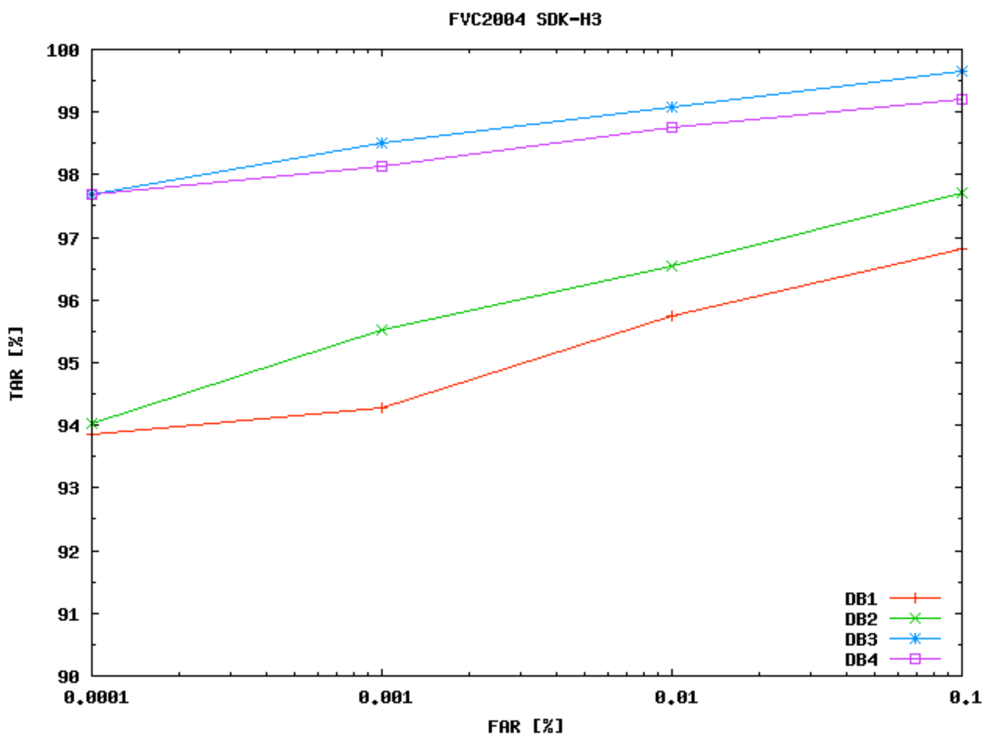
Appendix C: FVC2004 (2/8)

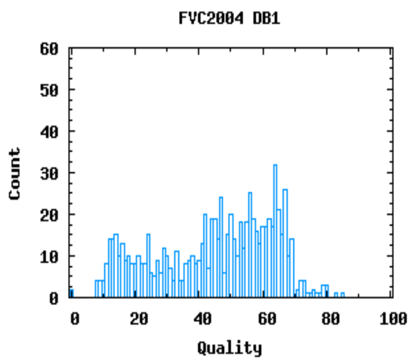
- **TAR at FAR=0.01%**

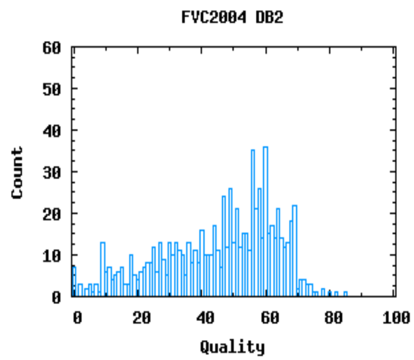
	Speed		TAR at FAR=0.01%			
	Match	FE	DB1	DB2	DB3	DB4
SDK H3	**H-equiv.**	**Slow**	**95.75**	**96.55**	**99.07**	**98.77**
SDK H2	H-equiv.	H-equiv.	95.66	95.09	98.70	97.96
SDK H	See NISTIR7151		93.63	94.88	97.79	97.02

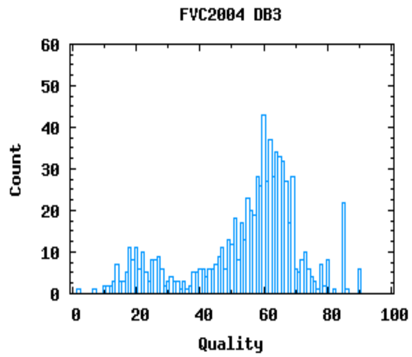
Appendix C: FVC2004 (3/8)

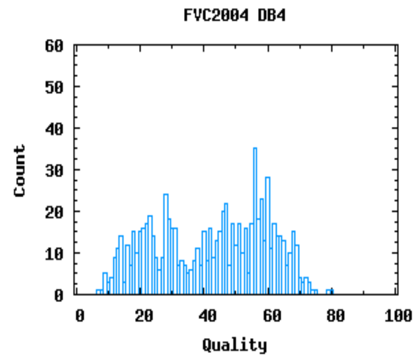
■ FAR vs TAR (SDK-H3)





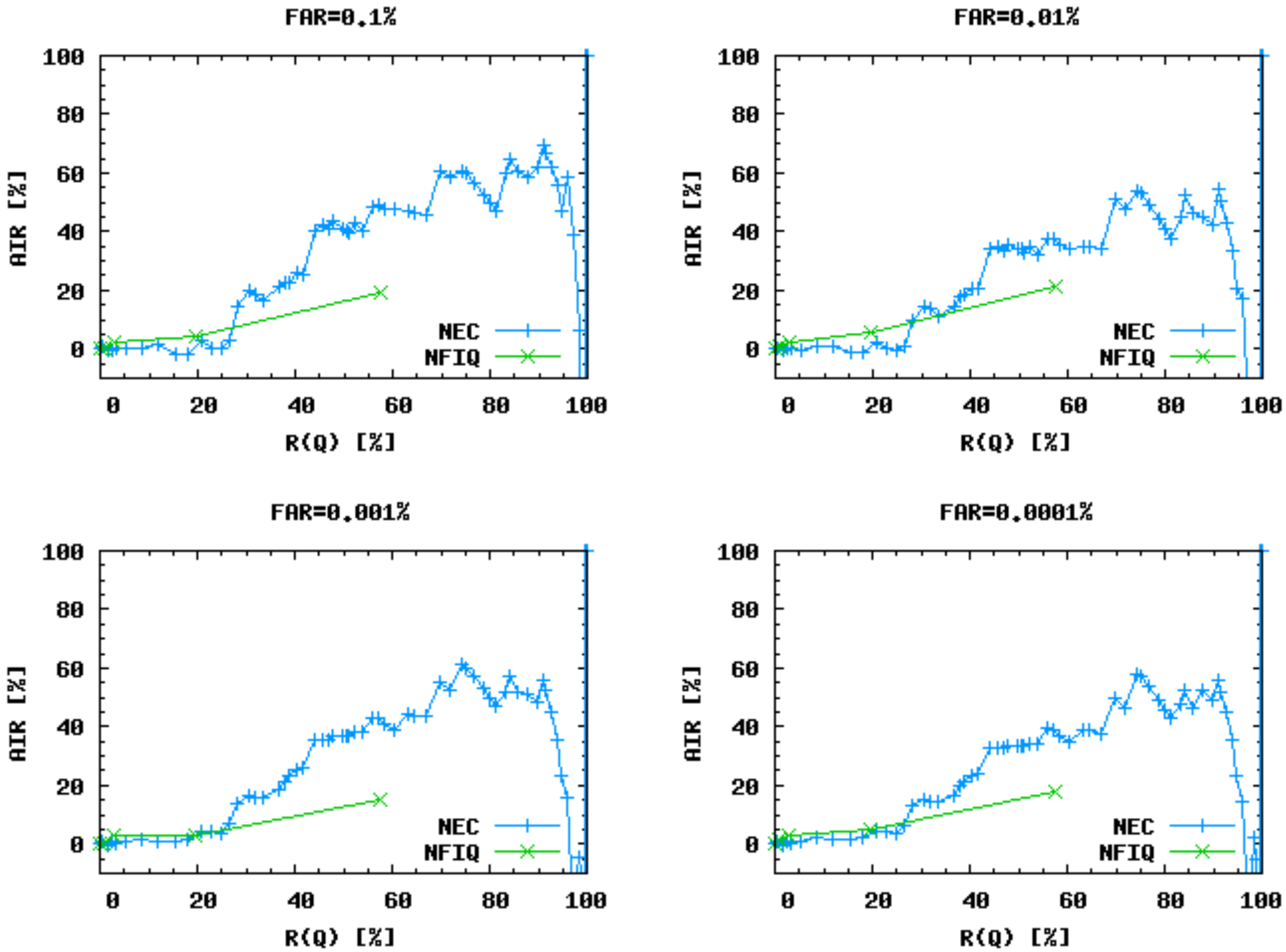






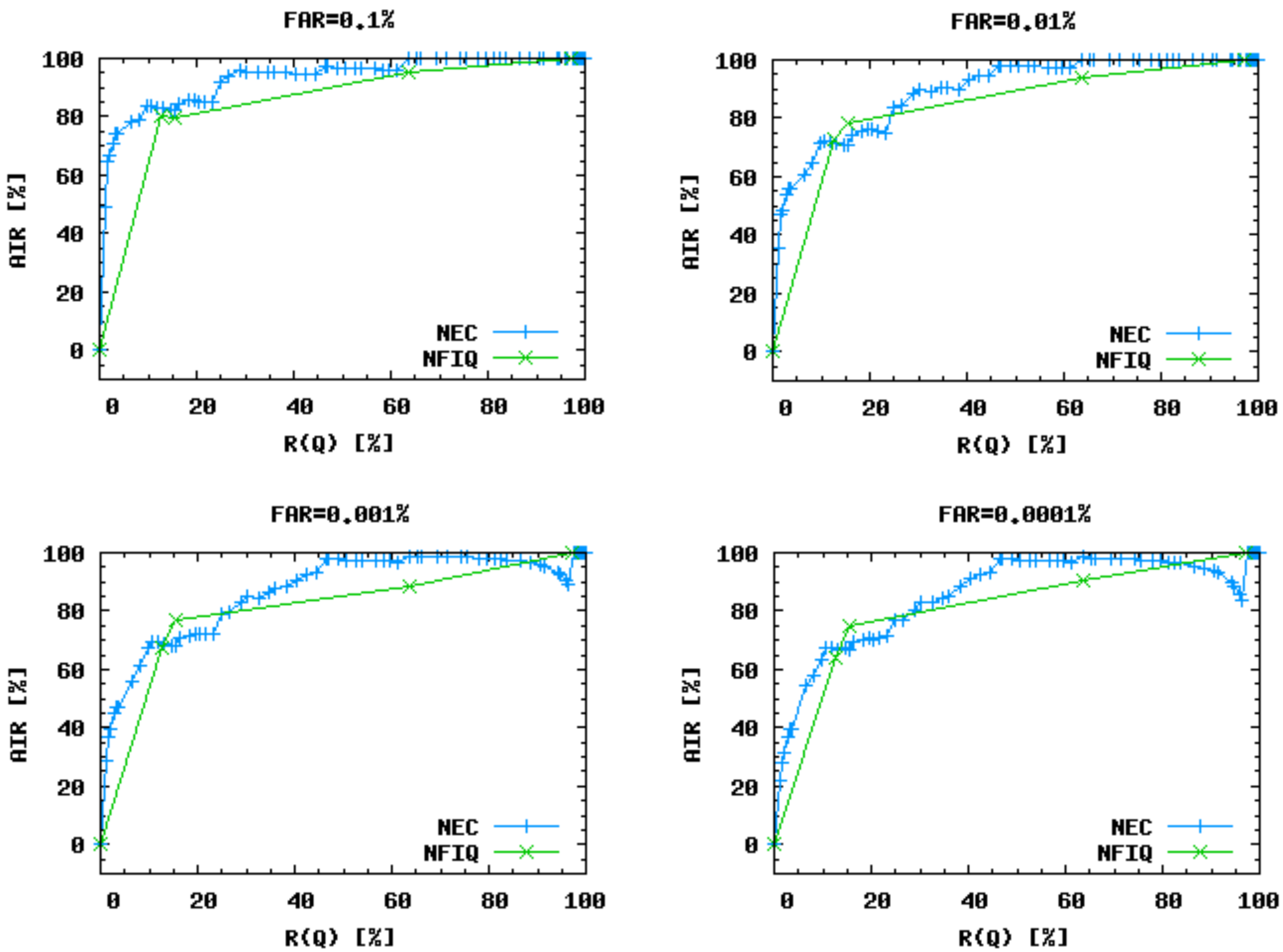
Appendix C: FVC2004 (4/8)

- DB1: Comparison over varying FAR



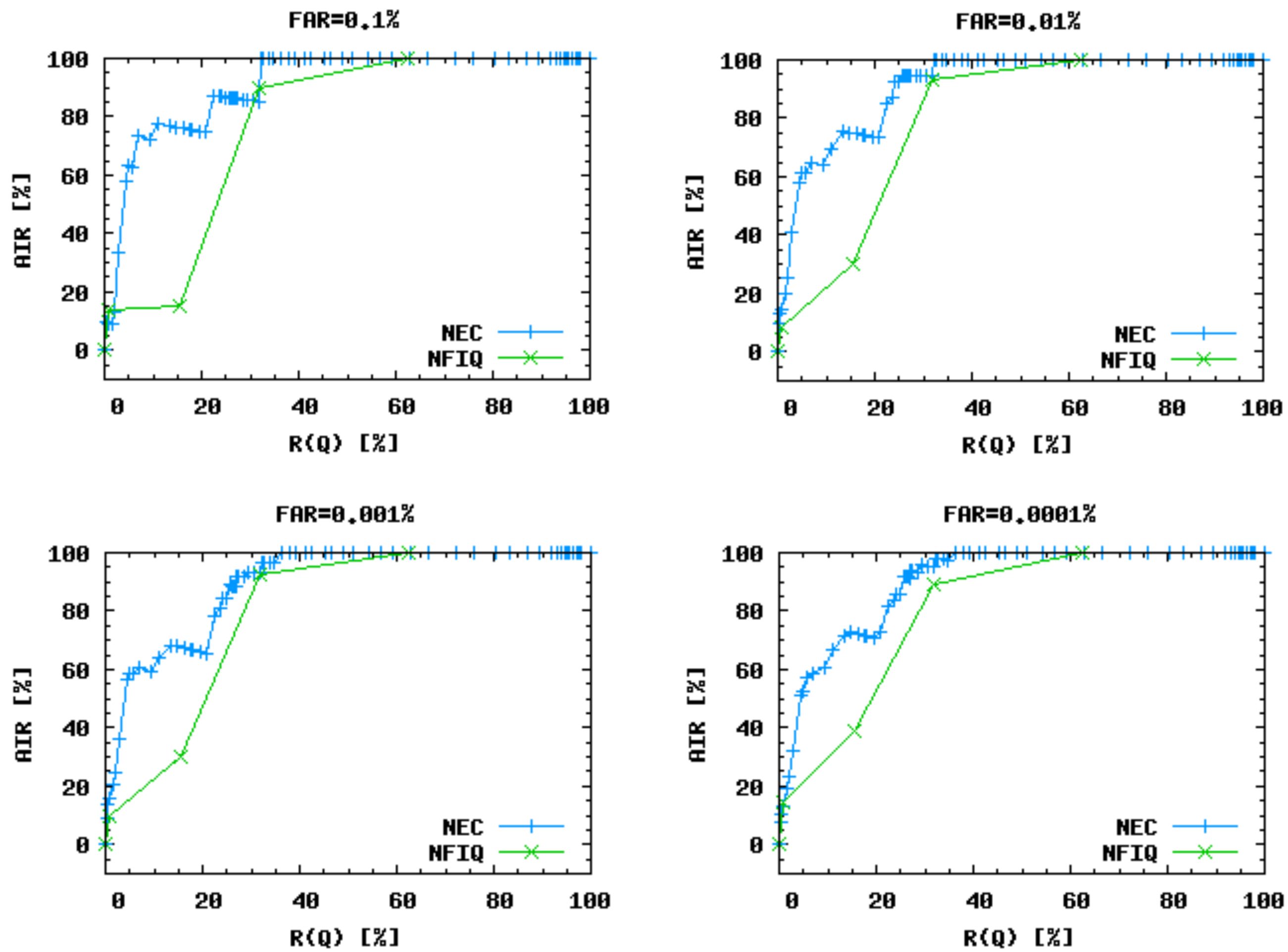
Appendix C: FVC2004 (5/8)

- **DB2: Comparison over varying FAR**



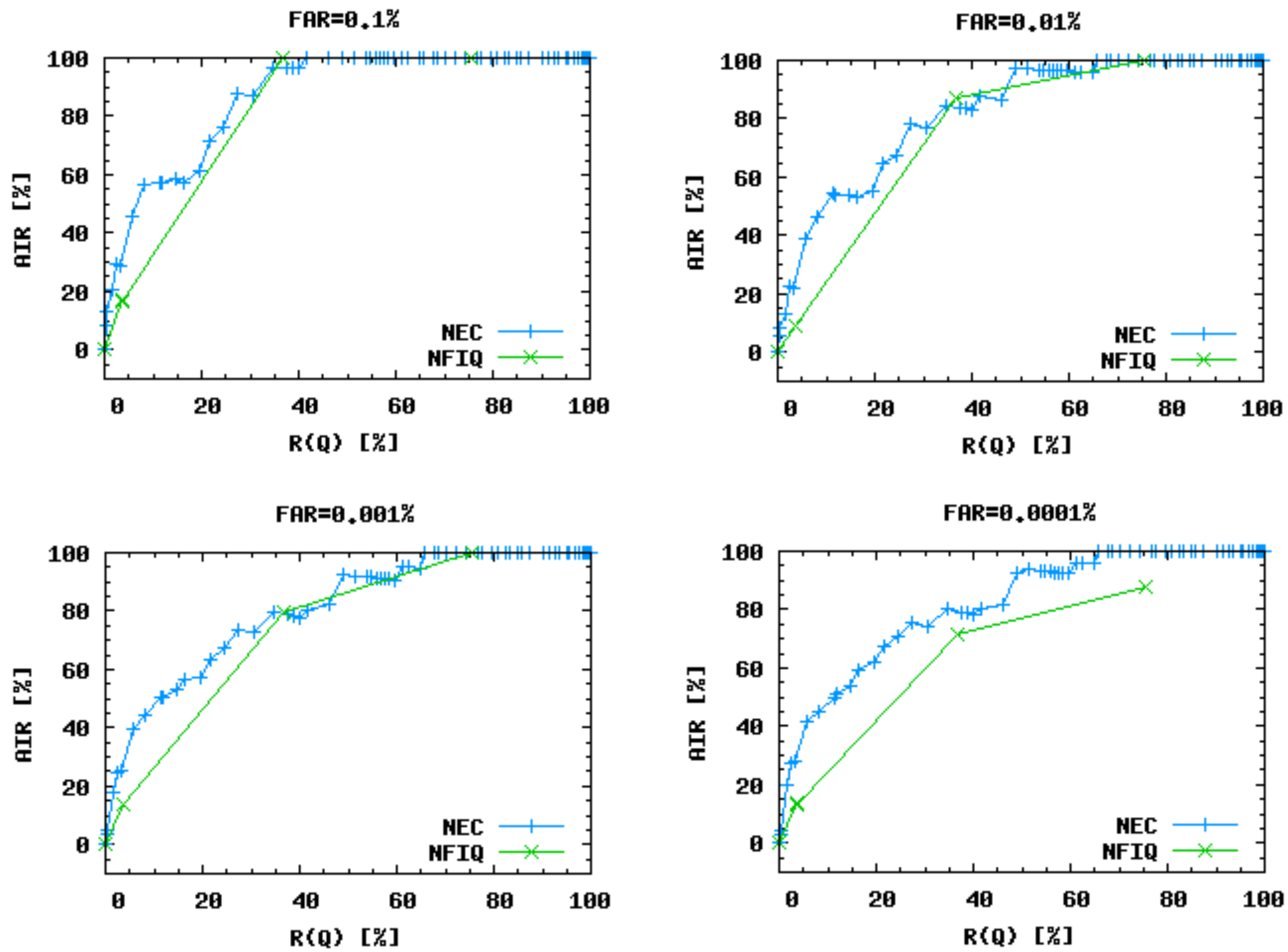
Appendix C: FVC2004 (6/8)

- **DB3: Comparison over varying FAR**

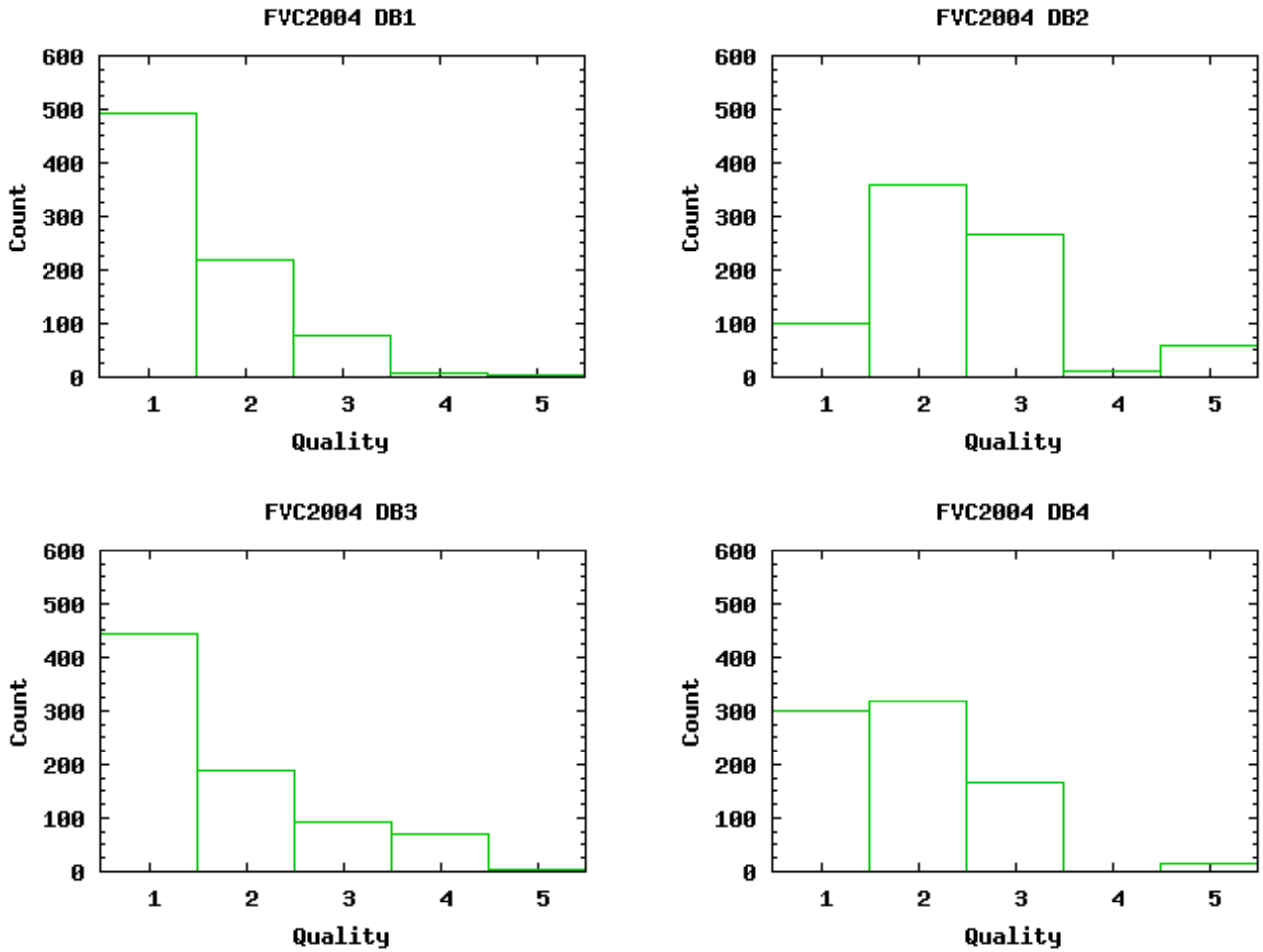


Appendix C: FVC2004 (7/8)

- **DB4: Comparison over varying FAR**



- NFIQ Quality Distribution

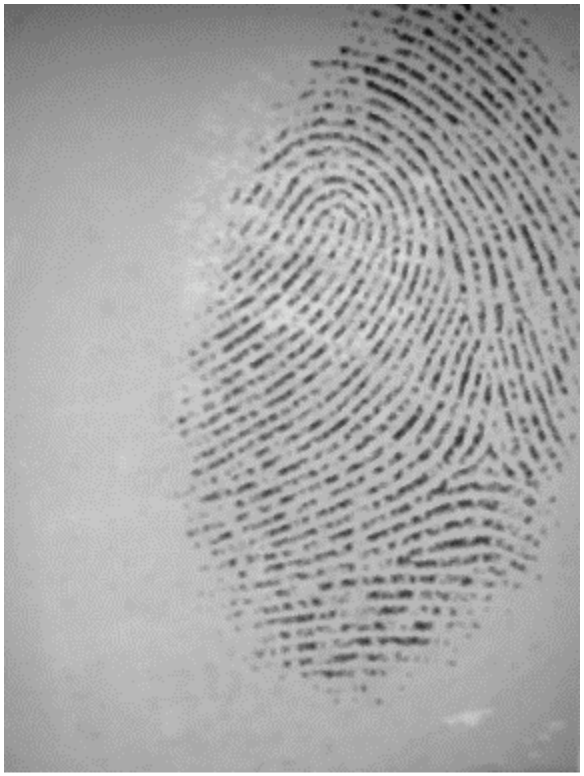


Appendix D: Remarks on Outliers

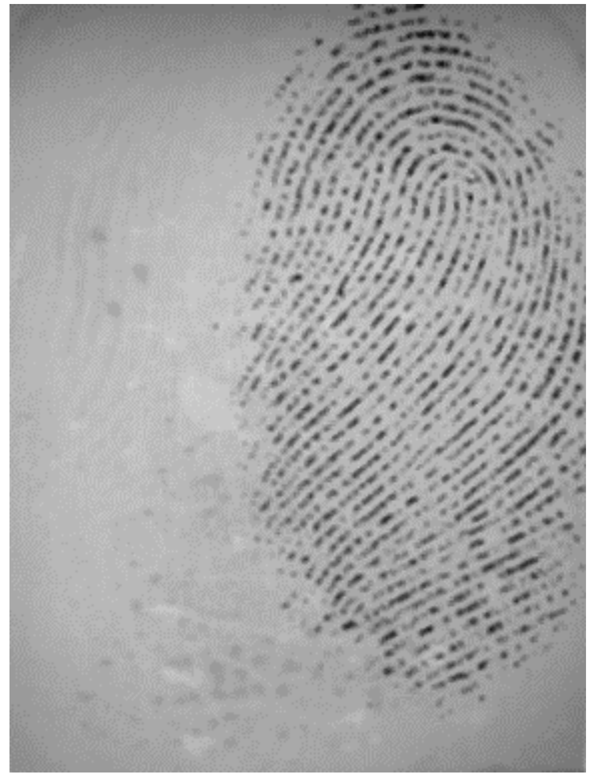
- A sharp drop of AIR at a high rejection rate observed (> 80%) is attributed to the fact that the denominator of the fraction used to calculate AIR is too small, and this overtakes the statistical fluctuation. Thus, this portion of the graph is statistically insignificant.
- Also note that this behavior is caused by high-quality images that resulted in low similarity scores (i.e., imperfect selectivity)

Appendix E: Problematic Images (1/2)

- FVC2002 DB4: Very few minutiae



$Q_{\mathrm{NEC}} = 35$



$Q_{\mathrm{NEC}} = 35$

Appendix E: Problematic Images (2/2)

- **FVC2004 DB1: Severely distorted**

$Q_{\mathrm{NEC}} = 68$

$Q_{\mathrm{NEC}} = 72$